Safety Improvements for Horizontal Curves

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March 6, 2019

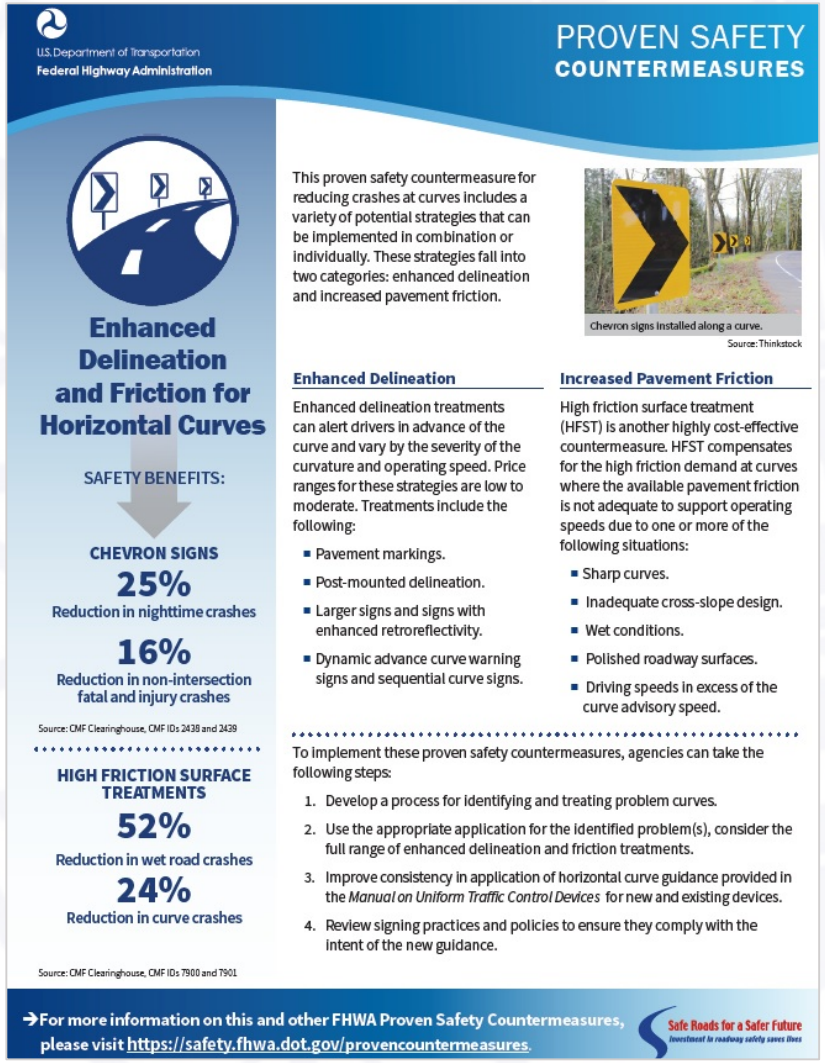
NextLevel INDIANA

Safety Improvements for Horizontal Curves

- Presentation Overview
  - Case Study
  - MUTCD Signing Requirements (§2C.06 - §2C.14)
    - Table 2C-5 on Horizontal Alignment Sign Selection
    - Advisory Speed Changes
    - Exceptions
  - 2015 NCHRP Study with Traffic Control Device Guidelines for Curves
  - INDOT HFST Projects
  - Conclusion

Presentation Overview (Cont'd)

Additional Resources: https://safety.fhwa.dot.gov/provencountermeasures/



U.S. Department of Transportation
Federal Highway Administration

PROVEN SAFETY COUNTERMEASURES

Enhanced Delineation and Friction for Horizontal Curves

SAFETY BENEFITS:

CHEVRON SIGNS

25%
Reduction in nighttime crashes

16%
Reduction in non-intersection fatal and injury crashes

Source: CMF Clearinghouse, CMF IDs 2438 and 2439

HIGH FRICTION SURFACE TREATMENTS

52%
Reduction in wet road crashes

24%
Reduction in curve crashes

Source: CMF Clearinghouse, CMF IDs 7900 and 7901

This proven safety countermeasure for reducing crashes at curves includes a variety of potential strategies that can be implemented in combination or individually. These strategies fall into two categories: enhanced delineation and increased pavement friction.

Chevron signs installed along a curve.
Source: Thinkstock

Enhanced Delineation

Enhanced delineation treatments can alert drivers in advance of the curve and vary by the severity of the curvature and operating speed. Price ranges for these strategies are low to moderate. Treatments include the following:

- Pavement markings.
- Post-mounted delineation.
- Larger signs and signs with enhanced retroreflectivity.
- Dynamic advance curve warning signs and sequential curve signs.

Increased Pavement Friction

High friction surface treatment (HFST) is another highly cost-effective countermeasure. HFST compensates for the high friction demand at curves where the available pavement friction is not adequate to support operating speeds due to one or more of the following situations:

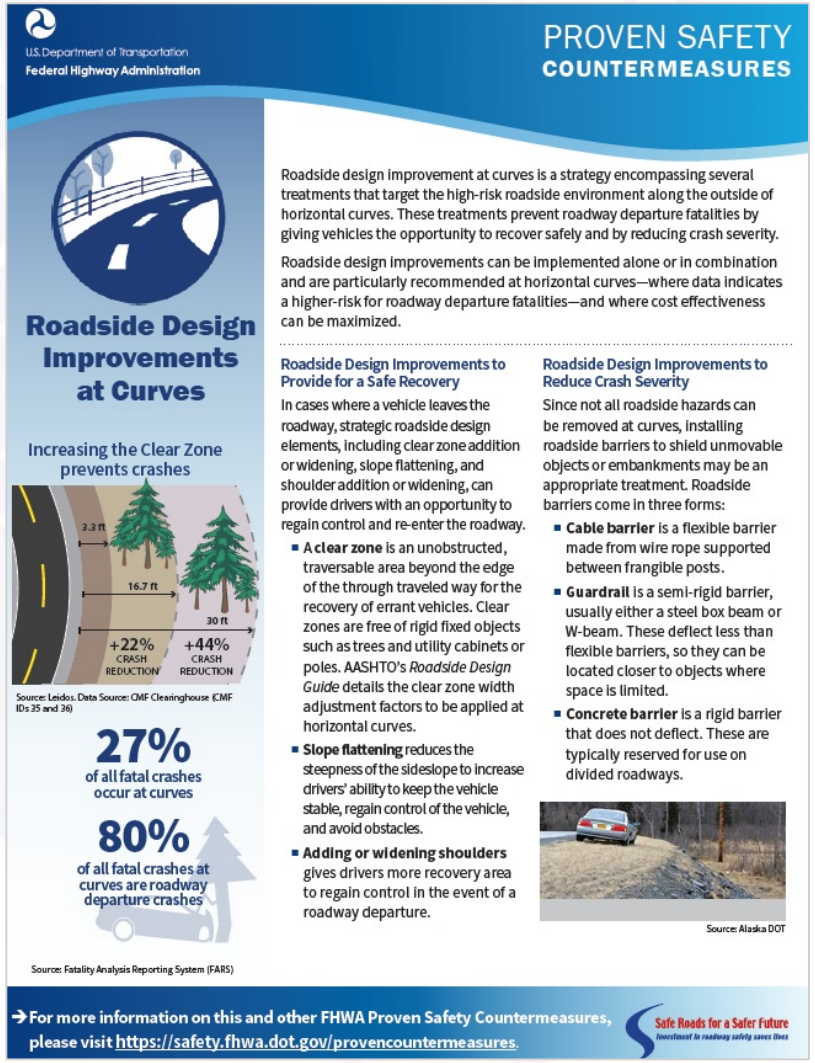
- Sharp curves.
- Inadequate cross-slope design.
- Wet conditions.
- Polished roadway surfaces.
- Driving speeds in excess of the curve advisory speed.

To implement these proven safety countermeasures, agencies can take the following steps:

1. Develop a process for identifying and treating problem curves.
2. Use the appropriate application for the identified problem(s), consider the full range of enhanced delineation and friction treatments.
3. Improve consistency in application of horizontal curve guidance provided in the *Manual on Uniform Traffic Control Devices* for new and existing devices.
4. Review signing practices and policies to ensure they comply with the intent of the new guidance.

→For more information on this and other FHWA Proven Safety Countermeasures, please visit https://safety.fhwa.dot.gov/provencountermeasures.

Safe Roads for a Safer Future
Investment in roadway safety saves lives



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PROVEN SAFETY COUNTERMEASURES

Roadside Design Improvements at Curves

Increasing the Clear Zone prevents crashes

Source: Leidos. Data Source: CMF Clearinghouse (CMF IDs 35 and 36)

27%
of all fatal crashes occur at curves

80%
of all fatal crashes at curves are roadway departure crashes

Source: Fatality Analysis Reporting System (FARS)

Roadside design improvement at curves is a strategy encompassing several treatments that target the high-risk roadside environment along the outside of horizontal curves. These treatments prevent roadway departure fatalities by giving vehicles the opportunity to recover safely and by reducing crash severity.

Roadside design improvements can be implemented alone or in combination and are particularly recommended at horizontal curves—where data indicates a higher-risk for roadway departure fatalities—and where cost effectiveness can be maximized.

Roadside Design Improvements to Provide for a Safe Recovery

In cases where a vehicle leaves the roadway, strategic roadside design elements, including clear zone addition or widening, slope flattening, and shoulder addition or widening, can provide drivers with an opportunity to regain control and re-enter the roadway.

- **A clear zone** is an unobstructed, traversable area beyond the edge of the through traveled way for the recovery of errant vehicles. Clear zones are free of rigid fixed objects such as trees and utility cabinets or poles. AASHTO's *Roadside Design Guide* details the clear zone width adjustment factors to be applied at horizontal curves.
- **Slope flattening** reduces the steepness of the sideslope to increase drivers' ability to keep the vehicle stable, regain control of the vehicle, and avoid obstacles.
- **Adding or widening shoulders** gives drivers more recovery area to regain control in the event of a roadway departure.

Roadside Design Improvements to Reduce Crash Severity

Since not all roadside hazards can be removed at curves, installing roadside barriers to shield unmovable objects or embankments may be an appropriate treatment. Roadside barriers come in three forms:

- **Cable barrier** is a flexible barrier made from wire rope supported between frangible posts.
- **Guardrail** is a semi-rigid barrier, usually either a steel box beam or W-beam. These deflect less than flexible barriers, so they can be located closer to objects where space is limited.
- **Concrete barrier** is a rigid barrier that does not deflect. These are typically reserved for use on divided roadways.

Source: Alaska DOT

→For more information on this and other FHWA Proven Safety Countermeasures, please visit https://safety.fhwa.dot.gov/provencountermeasures.

Safe Roads for a Safer Future
Investment in roadway safety saves lives

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Case Study

- SR 159 at Louisville Rd, Vigo County
  - INDOT loses 2012 lawsuit about horizontal curve signing
  - Jury awarded $250,000 to plaintiff for injuries sustained due to inadequate road signage (Gulley v. INDOT).

Case Study (Cont'd)

- SR 159 at Louisville Rd, Vigo County (Aerial View)

Case Study (Cont'd)

- SR 159 at Louisville Rd, Vigo County (2005 Videolog Image 1)

Case Study (Cont'd)

- SR 159 at Louisville Rd, Vigo County (2005 Videolog Image 2)

Case Study (Cont'd)

Additional Resource

October 2014

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Legal Research Digest 63

EFFECT OF MUTCD ON TORT LIABILITY OF GOVERNMENT TRANSPORTATION AGENCIES

This report was prepared under NCHRP Project 20-6, "Legal Problems Arising Out of Highway Programs," for which the Transportation Research Board is the agency coordinating the research. The report was prepared by Larry W. Thomas, The Thomas Law Firm, Washington, DC. James B. McDaniel, TRB Counsel for Legal Research Projects, was the principal investigator and content editor.

The Problem and Its Solution

State highway departments and transportation agencies have a continuing need to keep abreast of operating practices and legal elements of specific problems in highway law. This report continues NCHRP's practice of keeping departments up-to-date on laws that will affect their operations.

Applications

The most recent version of the *Manual on Uniform Traffic Control Devices* (MUTCD) was adopted by the U.S. Department of Transportation on December 16, 2009, to be effective January 15, 2010. The final rulemaking (74 *Federal Register* 66729) also required that, within 2 years of the effective date, states adopt the MUTCD as their legal state standard for traffic control devices. The MUTCD, administered by the Federal Highway Administration since 1971, has been revised a number of times over the years, with the most recent previous edition being adopted in 2003. The 2009 revision made changes to some compliance dates, as well as language changes, that may impact on states' possible tort liability.

This research was undertaken to inform practitioners about the current status of tort liability involving governmental transportation agencies arising from the application and development of the MUTCD. Research explores the basis for tort liability arising before and after adoption of the MUTCD. This includes issues relating to governmental immunity, such as mandatory versus permissive language and the "planning/operational" test to determine governmental liability, which are considered and discussed in *NCHRP Legal Research Digest 38: Risk Management for Transportation Programs Employing Written Guidelines as Design and Performance Standards* (1997). Virtually all states and localities permit a plaintiff to sue a public entity for negligence, subject, however, to certain limitations and exceptions. As discussed in this digest, tort claims acts that apply to transportation departments and other public entities generally include a discretionary function exemption to immunize public entities for alleged negligence when exercising their discretion. In addition, a state's tort claims act or other state statute may include additional exceptions to the liability of transportation departments.

Issues that that are addressed include: 1) the effect of the MUTCD on the manner in which government tort liability has developed; 2) the extent to which federal, state, and other governments have adopted tort claims acts and laws that have waived or greatly curtailed sovereign immunity; and 3) the impact of peculiar state laws.

This digest should be useful to highway attorneys, safety officials, budget planners, and state highway officials in general.

TRANSPORTATION RESEARCH BOARD
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- Questions from Case
  - Under the 2011 IMUTCD is the advance horizontal alignment warning sign correct for a combined curve/intersection?
  - Is a single large arrow sign sufficient for the in-curve signing?

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2011 IMUTCD Requirements (Cont'd)

Table 2C-5. Horizontal Alignment Sign Selection

Type of Horizontal Alignment Sign	Difference Between Speed Limit and Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W10-1) (see Section 2C.07 to determine which sign to use)	Recommended	Required	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Recommended	Required	Required	Required	Required
Chevrons (W1-8) and/or One Direction Large Arrow (W1-6)	Optional	Recommended	Required	Required	Required
Exit Speed (W13-2) and Ramp Speed (W13-3) on exit ramp	Optional	Optional	Recommended	Required	Required

Note: Required means that the sign and/or plaque shall be used, recommended means that the sign and/or plaque should be used, and optional means that the sign and/or plaque may be used.

See Section 2C.06 for roadways with less than 1,000 ADT.

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Old 2008 IMUTCD Table 2C-5

Old 2008 ***Table 2C-5. Horizontal Alignment Sign Usage***

Number of Alignment Changes	Advisory Speed	
	≤ 50 km/h (≤ 30 MPH)	> 50 km/h (> 30 MPH)
1	Turn (W1-1)[1]	Curve (W1-2)[1]
2[2]	Reverse Turn[3] (W1-3)	Reverse Curve[3] (W1-4)
3 or more[2]	Winding Road[3] (W1-5)	

Notes:

[1] Engineering judgment should be used to determine whether the Turn or Curve sign should be used.

[2] Alignment changes are in opposite directions and are separated by a tangent distance of 180 m (600 ft) or less.

[3] A Right Reverse Turn (W1-3R), Right Reverse Curve (W1-4R), or Right Winding Road (W1-5R) sign is used if the first change in alignment is to the right; a Left Reverse Turn (W1-3L), Left Reverse Curve (W1-4L), or Left Winding Road (W1-5L) sign is used if the first change in alignment is to the left.

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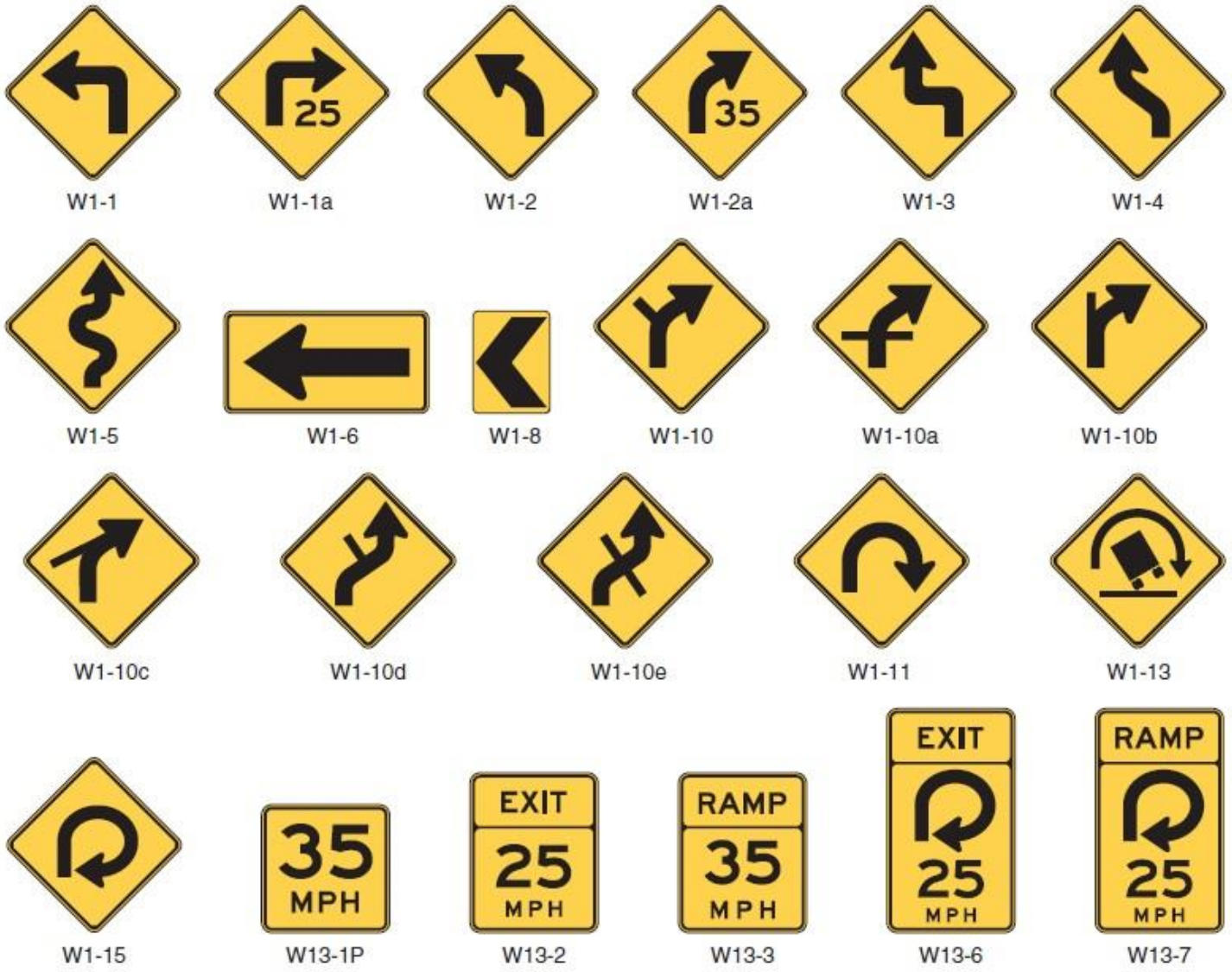
IMUTCD Requirements (Cont'd)

Figure 2C-1. Horizontal Alignment Signs and Plaques

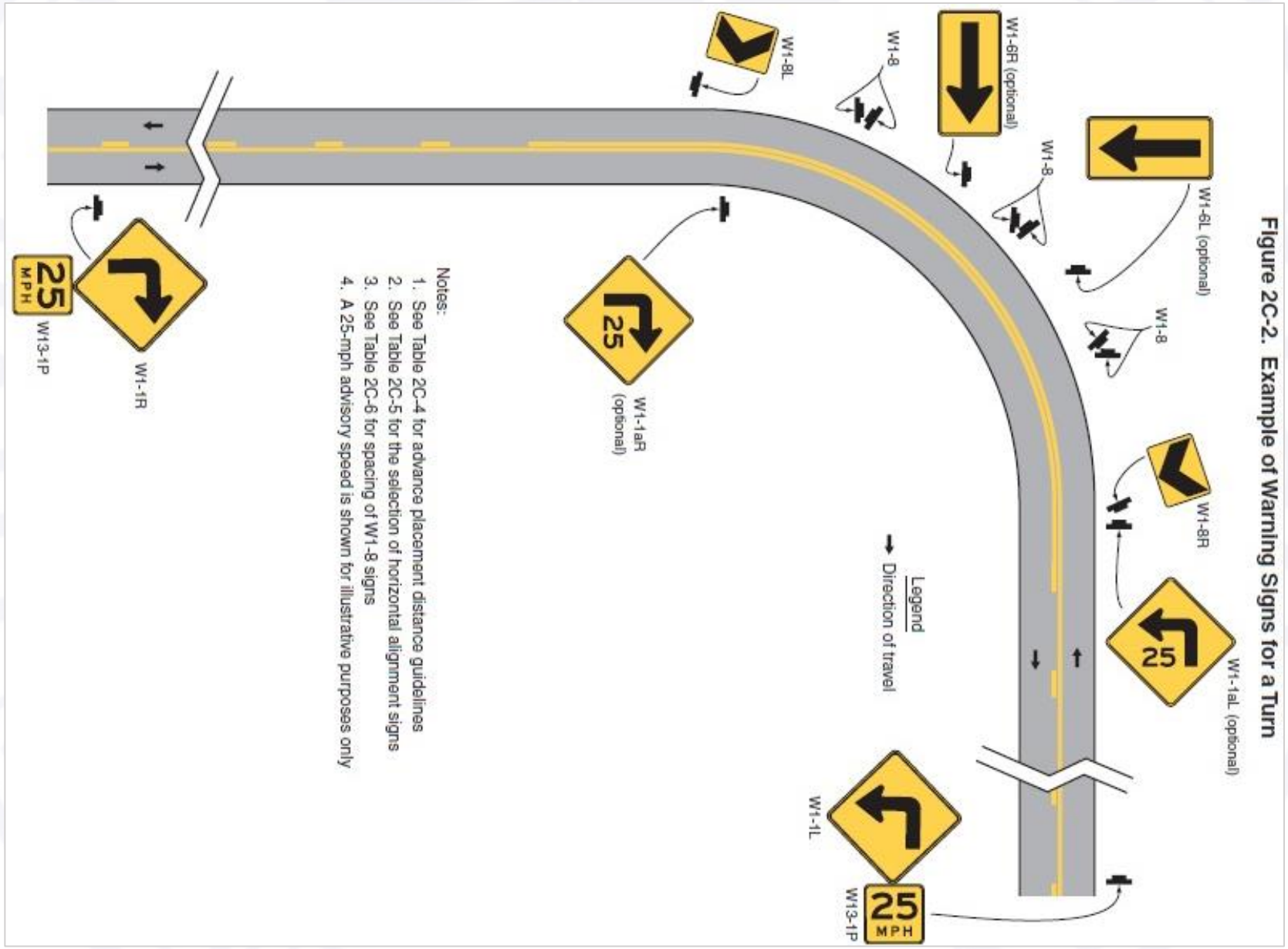


IMUTCD Requirements (Cont'd)

- §2C.11 Combination Horizontal Alignment/Intersection Signs (W1-10 Series)
  - A turn (W1-1) or curve (W1-2) sign **may** be combined with a cross road (W2-1) sign or a side road (W2-2, W2-3) sign to create a combination horizontal alignment/intersection sign.
  - No more than one cross road or two side roads should be used.

W1-10bL W1-Y1CL W10-YCR

IMUTCD Requirements (Cont'd)



IMUTCD Requirements (Cont'd)

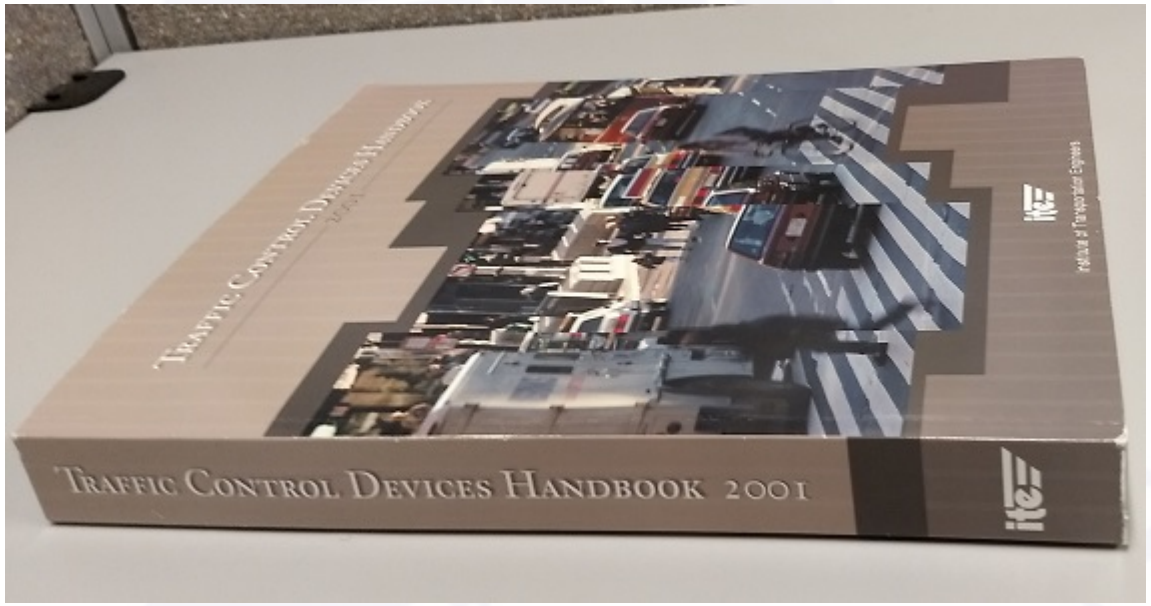
Table 2C-6. Typical Spacing of Chevron Alignment Signs on Horizontal Curves

Advisory Speed	Curve Radius	Sign Spacing
15 mph or less	Less than 200 feet	40 feet
20 to 30 mph	200 to 400 feet	80 feet
35 to 45 mph	401 to 700 feet	120 feet
50 to 60 mph	701 to 1,250 feet	160 feet
More than 60 mph	More than 1,250 feet	200 feet

Note: The relationship between the curve radius and the advisory speed shown in this table should not be used to determine the advisory speed.

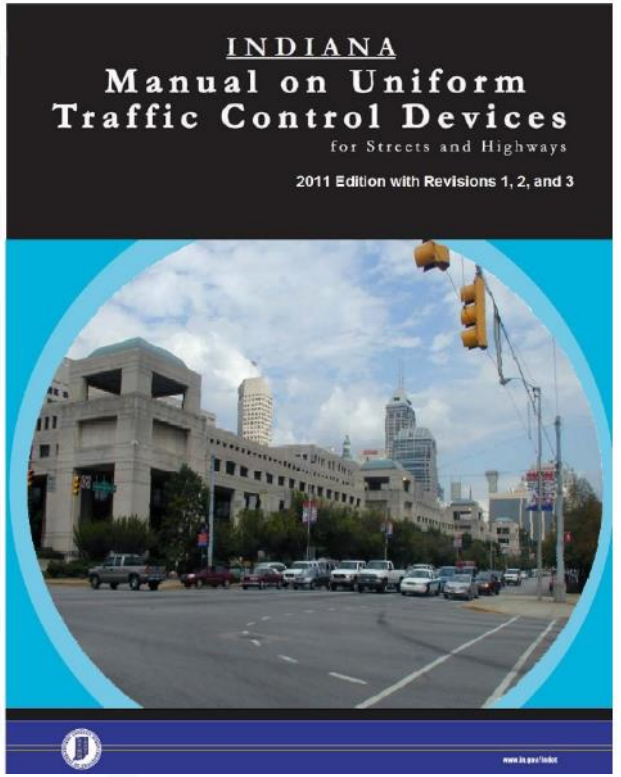
Setting Advisory Speeds

- 2001 ITE Traffic Control Devices Handbook Ball Bank Procedures
  - 14 degrees of ball-bank for speeds of 20 mph or less
  - 12 degrees of ball-bank for speeds of 25 to 30 mph
  - 10 degrees of ball-bank for speeds of 35 mph and higher



Setting Advisory Speeds (Cont'd)

- 2011 IMUTCD Ball Bank Procedures in §2C.08
  - 16 degrees of ball-bank for speeds of 20 mph or less
  - 14 degrees of ball-bank for speeds of 25 to 30 mph
  - 12 degrees of ball-bank for speeds of 35 mph and higher
  - The 16, 14, and 12 degrees of ball-bank criteria are comparable to the current AASHTO horizontal curve design guidance.



Setting Advisory Speeds (Cont'd)

- Ball Bank Study Products and Services (No Endorsement)

MECHANICAL INCLINOMETERS

1023W1 Mechanical Inclinometer | Ball Bank Indicator

$82.00

CARS: CURVE ADVISORY REPORTING S...

CARS (Curve Advisory Reporting Service)

ELECTRONIC SENSORS

RDS7-BB-09 Digital Ball Bank Indicator

$704.44

Rieker Products and Services

V-SENSE RG
ROAD GEOMETRY / CURVE AUDIT SYSTEM
1-PASS ROAD AUDIT

$4,675.00

P/N 530850-RG

Add to Cart

Vericom Product

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IMUTCD Target Compliance Date (from Table I-2)

December 31, 2019

(in 300 days)

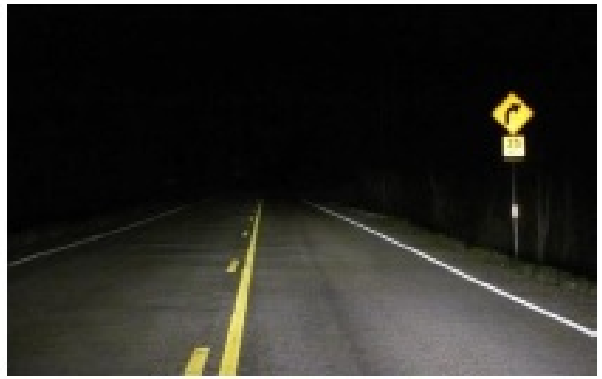
Exceptions

- Low AADT (<1000); **or**
- Roadway functional classification status below collector

- Chevrons (W1-8) are not required if a One-Direction Large Arrow, also known as a night arrow sign (W1-6) is used.

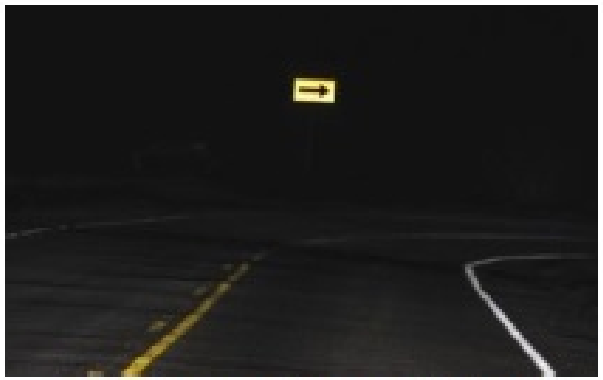
Traffic Control Device Guidelines for Curves

- 2015 Study by Paul Carlson and Bradford Brimley with TTI (NCHRP 03-106)
  - Reviewed traffic control device applications for curves



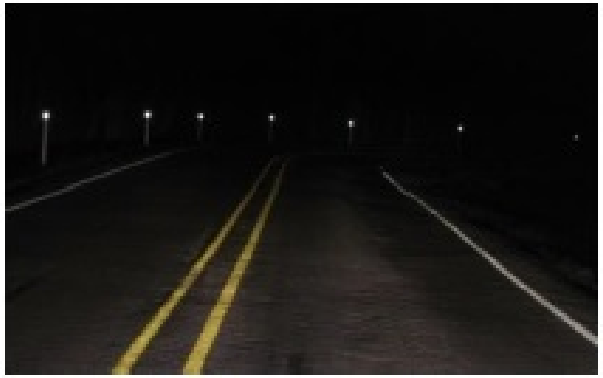
(a) Curve Sign

(b) Chevrons



(c) Large Arrow Sign

(d) RPMs



(e) Delineators

Traffic Control Device Guidelines for Curves

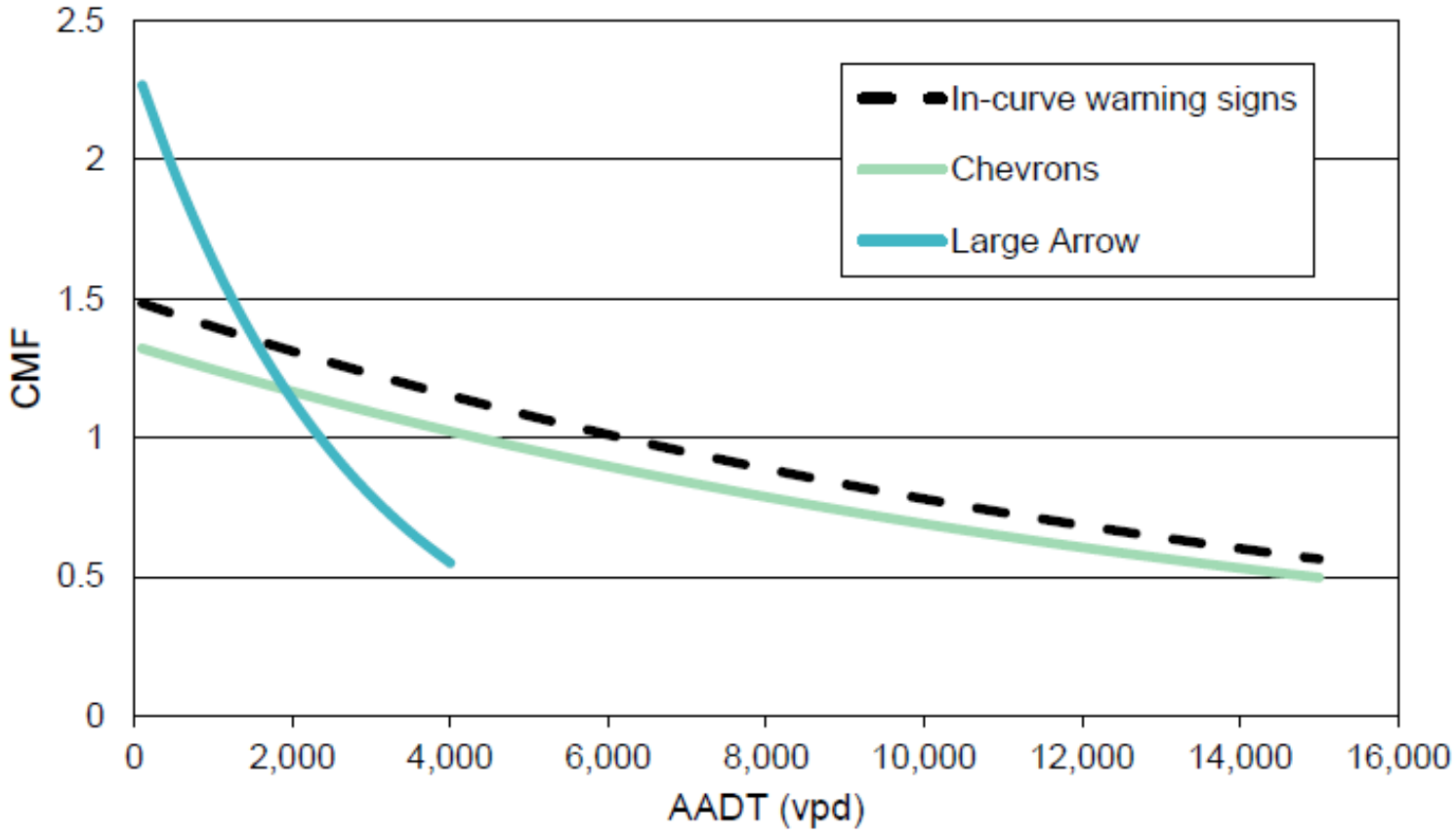
- NCHRP 03-106 Research (Cont'd)
  - Included Driver Behavior Study
  - 103 participants and 4,800 driver observations (3 states ID, OR, TX)

Effects of TCDs on Curve Navigation Models

Treatment	Effect on Speed at PC (mph)	Effect on Deceleration Rate (ft/s^2)	Effect on Lateral Acceleration (g)
Curve sign	−0.88	Not significant	Not significant
Delineators	−2.3	−0.93	−0.018
Large Arrow	−2.7	−0.85	−0.0098
Chevrons	−2.5	−0.94	−0.026
RPMs	Not significant	−0.23	Not significant

Traffic Control Device Guidelines for Curves

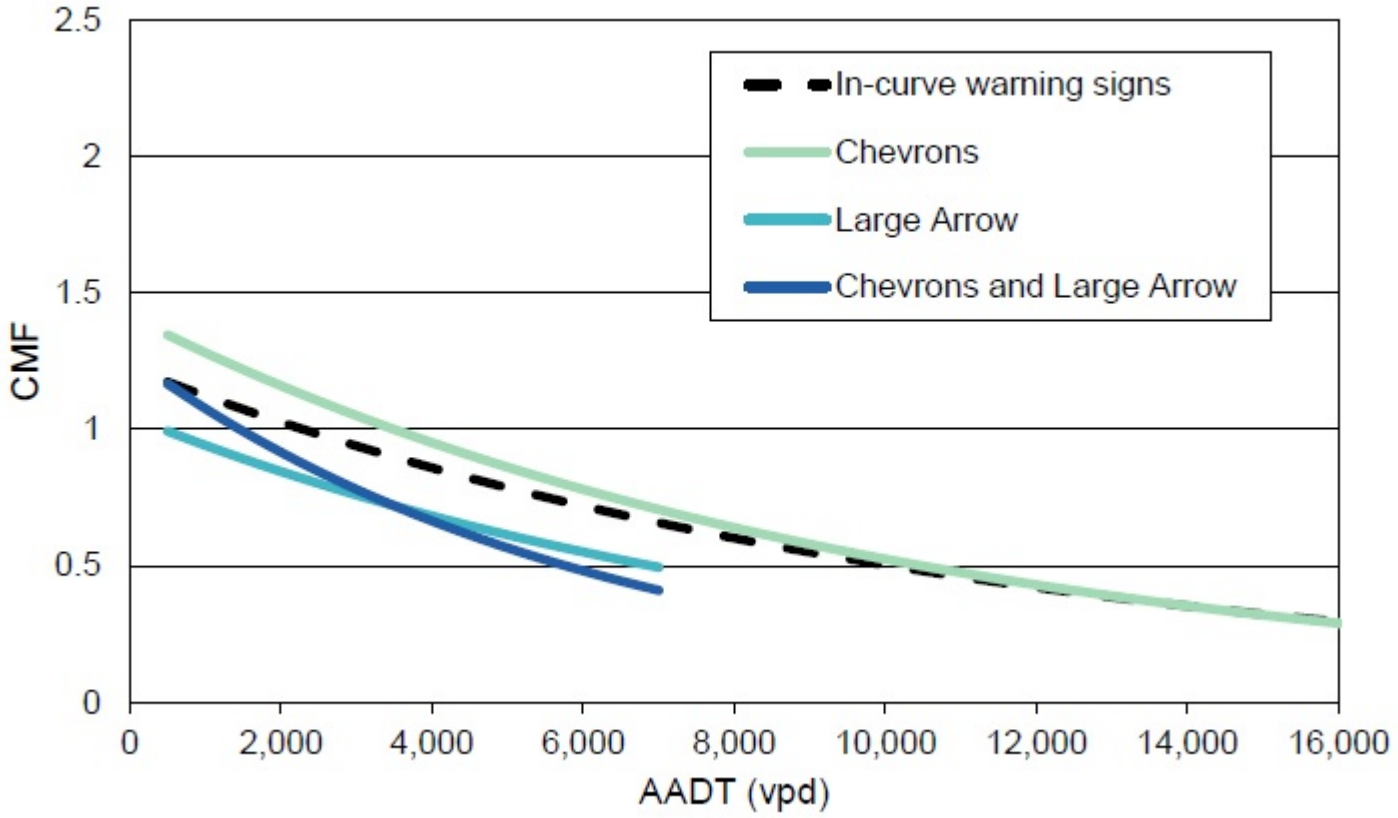
- NCHRP 03-106 Research (Cont'd)
  - Included Safety Analysis
  - 271 isolated curves and 270 curve series (4 states FL, OH, OR, TN)



Safety Performance at Curve Series

Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont'd)
  - In-curve warning signs are chevrons and large arrow signs located in the curve (dashed line below represents aggregate of data)



Safety Performance at Isolated Curves

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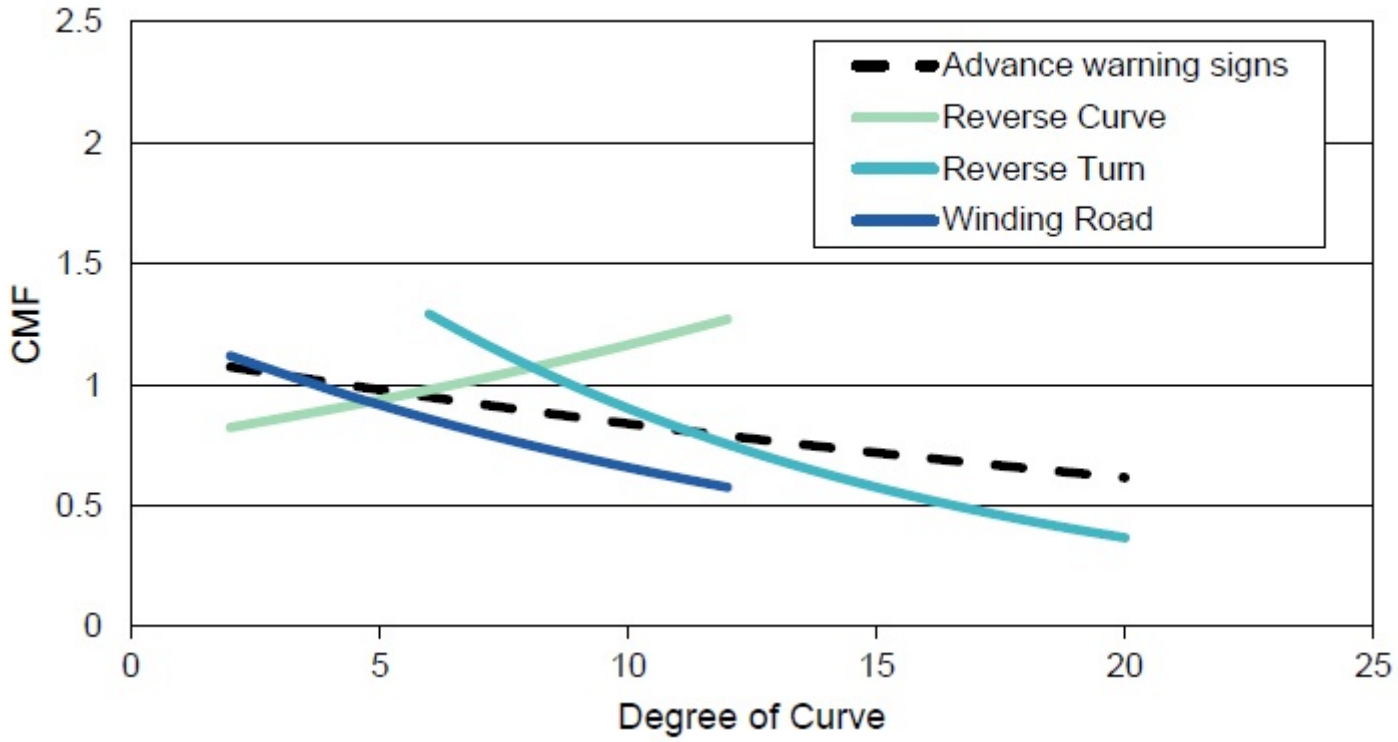
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont'd)
  - Advance warning signs are curve, turn, and winding road (dashed line below represents aggregate of data)



Safety Performance of Curve and Turn Signs in Curve Series

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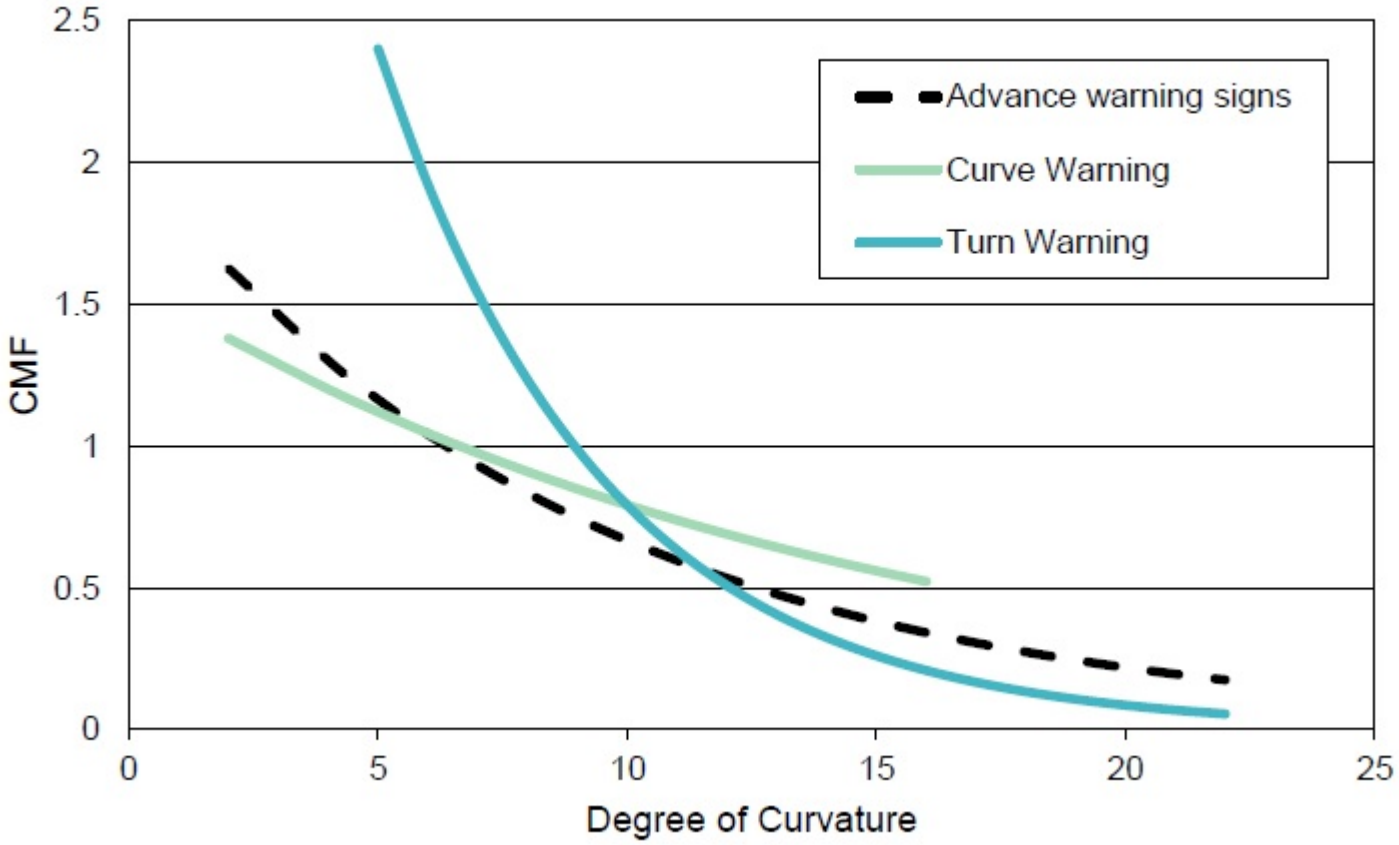
Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont'd)
  - Turn signs are more effective than curve signs when the degree of curvature is greater than 10 degrees (radius less than ~600 ft).



Safety Performance of Curve and Turn Signs at Isolated Curves

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Traffic Control Device Guidelines for Curves

- NCHRP 03-106 Research (Cont'd)

Table 2C-5. Selection of Devices for Changes in Horizontal Alignment[14]

Speed Limit[a] (mph)	Devices for Curve Advisory Speed (mph)[b]										
	20	25	30	35	40	45	50	55	60	65	70
25	M[c]	—	—	—	—	—	—	—	—	—	—
30	W	M[c]	—	—	—	—	—	—	—	—	—
35	D	W	M[c]	—	—	—	—	—	—	—	—
40	D	D	W	M[c]	—	—	—	—	—	—	—
45	D	D	D	W	M[c]	—	—	—	—	—	—
50	C	C	D	D	W	M[c]	—	—	—	—	—
55	C	C	C	D	D	W	M[c]	—	—	—	—
60	C	C	C	C	D	D	W	M[c]	—	—	—
65	C	C	C	C	C	D	D	W	M[c]	—	—
70	C	C	C	C	C	C	C	D	W	M[c]	—
75	C	C	C	C	C	C	C	C	D	W	M[c]

Notes:

[a]The 85th percentile speed may be used in place of the speed limit (Section 2C.06a, Paragraph 06).

[b]Device abbreviations: M – markings, W – advance warning sign, D – delineators plus advance warning sign, C – chevrons plus advance warning sign.

[c]An advance warning sign shall be used on roads without pavement markings as defined in Section 2C.06a, Paragraph 01.

Recommended MUTCD Revision

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AASHTO Request for Revision or Extension

- AASHTO has requested FHWA revise Chapter 2C based on these findings and issue an interim approval.
- The request also asked FHWA to consider extending the target compliance date by ten years to 12/31/2029.
- FHWA has not responded to the request as of 3/6/2019.

INDOT Curve Sign & Marking Visibility Projects

- District Contracts
  - 8 contracts (to date)

    T-35109
    RS-36046 (incl. resurfacing)
    T-39138
    T-39148
    T-36591
    T-39130
    T-39140
    T-39984
  - $2 million spent (to date)

INDOT High Friction Surface Treatment Projects

- High Friction Surface Treatments (HFST)
  - Consist of a high friction aggregate (primarily calcined bauxite) set in a polymer resin binder.
  - HFST was first developed in Europe in the 1960's and has now been installed in over 44 states.
  - INDOT has let 2 contracts (T-40130 and R-40695) to apply HFST at 25 curves

Eastbound US 24 at CR 50 S, near Reynolds, White County

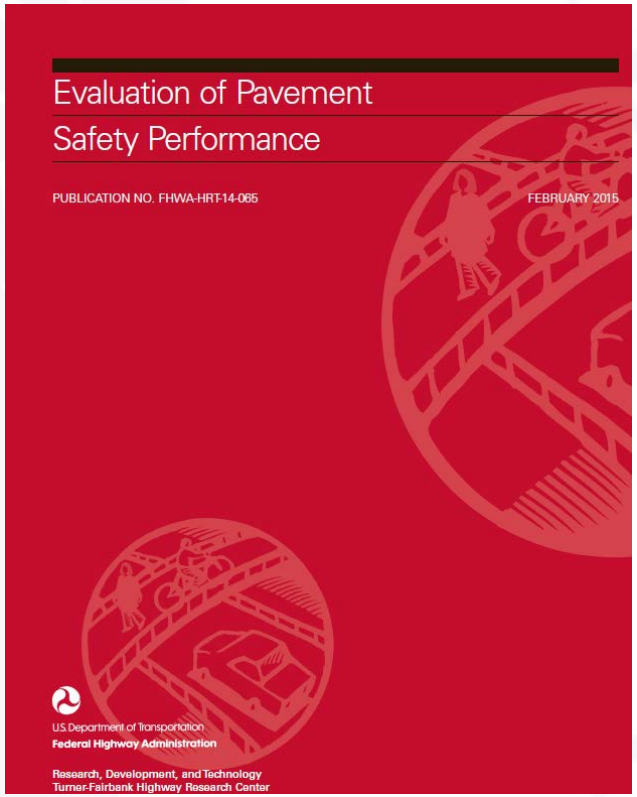
Westbound SR 32 at SR 47 (w jct), near Crawfordsville, Montgomery County

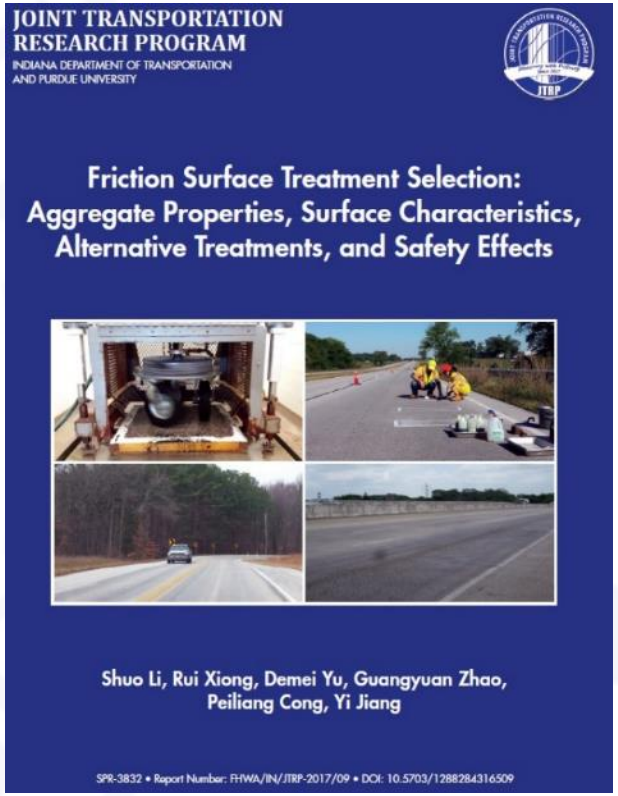
INDOT HFST Projects (Cont'd)

- Expectations for HFST Projects
  - Service Life ~ 10 years
  - Cost ~ $17 /sys (weighted average from T-40130 and R-40695)
  - Crash Modification Factor ~ 0.52

  (Some locations have a higher level of crash reductions)

Additional Resources





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INDOT HFST Projects (Cont'd)

- INDOT HFST Pay Item Data (to date)

High Friction Surface Treatment			
Pay Item 617-12128			
Contract	Quantity (sys)	Unit Price (per sys)	Cost
T-40130	51,168	$16.10	$823,804
R-40695	8,079	$19.50	$157,541
Totals:	59,247	$16.56	$981,345

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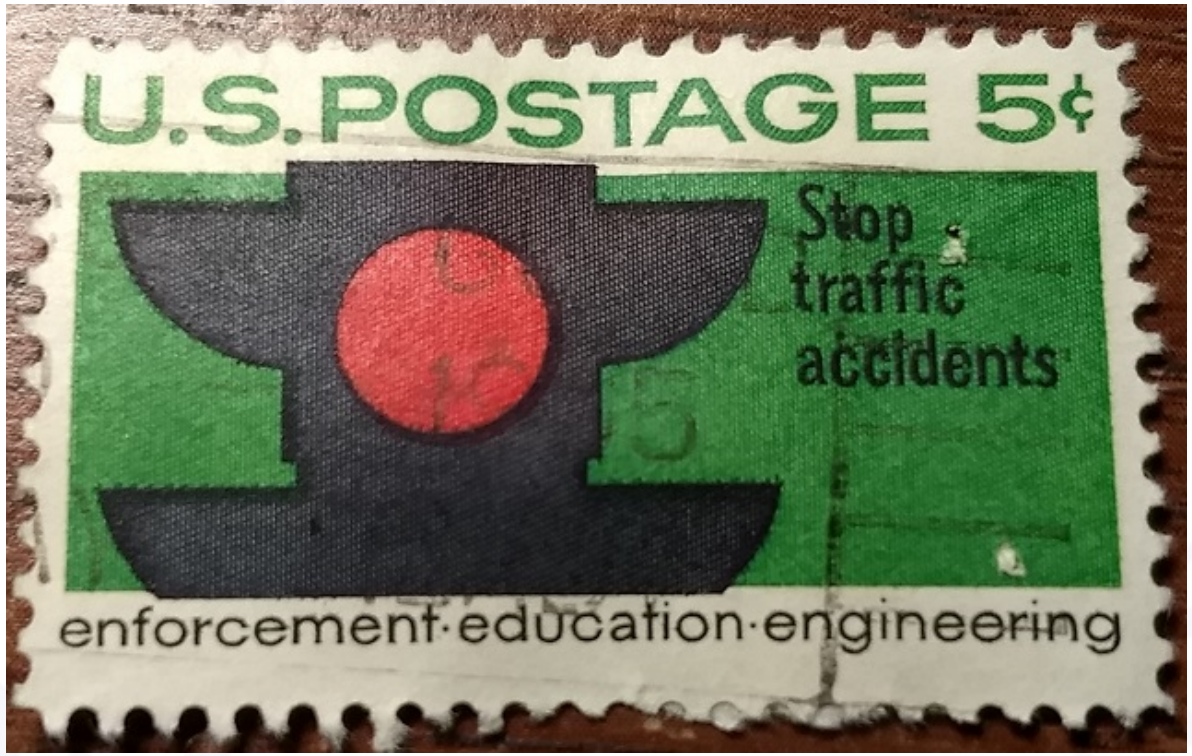
Summary

- Takeaways
  - Advisory speeds set prior to the 2011 IMUTCD need to be reviewed
  - Review horizontal alignment signs and traffic control devices at horizontal curves.
  - Current MUTCD Compliance Deadline of 12/31/2019



Conclusion

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